Population Density and Criteria for Cabling of Overhead Lines

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Abstract

Development of the civilization should be supported by adequate line infrastructure. This infrastructure connects urban areas, however it also affects their future growth. The collision of both of them needs substantial attention and study. Power network presents one of the line infrastructures, which is necessary for operation and development of settlements, although it limits the construction of buildings in its vicinity.

In Slovenia, it was allowed to construct overhead lines over residential areas, and building houses under conductors was acceptable. But recently, changes in the legislation took place and new regulations limit the construction of residences within overhead line corridors, and, in addition, new lines should avoid crossing existing housing areas. The public would like to see the problem of overhead lines in the vicinity of residences to be solved by either cabling or moving the lines to a different location.

Recently, the public called out for the corridors to be expanded, but this would cause a number of issues for many houses and thus generate additional costs. The results of our study speak in favour of the assumption that corridors are less populated than outside space.

Due to limitations in possible increases of transmission fees, it is impossible to cater to all wishes. Therefore, it is necessary to establish criteria that would ensure that the outcomes for people in the vicinity of overhead power lines are indeed fair and consistent. The following paper presents a contemporary method of defining and establishing housing density in corridors as a basis for cabling criteria.

We present a proposal focused on how it might be possible to determine criteria for cabling that would apply to the entire state. The proposal of criteria for cabling defines sections of overhead transmission lines which might be replaced with underground cables according to the population density of settlements. However, before applying the newly established criteria, technical restrictions should be taken into account.

Keywords

Population Density; Criterion; Transmission; Corridor

Introduction

Power network of Slovenia was built in accordance with technical and economic rules, but without accounting many environmental restrictions. Regulations permitted the construction of overhead lines above buildings and vice versa, namely building houses beneath them was possible as well.

Rules on the conditions and limitations of the works, the use of facilities and activity in the corridors of electricity networks limit the construction of new houses in the corridors of overhead lines. Also these strict regulations bound the construction of new, and the replacement of existing overhead lines in the vicinity of existing homes.

First we defined different widths of corridors, then we established the number of houses in them and after that we calculated the density of housing in these corridors.

Due to limitations in available financial resources that are funded by transmission fees, it is necessary to establish criteria which ensure that the solution takes into account the density of housing and thus provides a basis for unbiased treatment. Our criterion sets the sequence of areas from the densely populated areas to those with lower density of houses. This sequence also suggests the order in which the overhead transmission line sections would be cabled.

Overhead Line Corridors and Transmission System

In the past the corridors' widths were determined as 2 x 25 m for 400 kV, 2 x 20 m for 220 kV and 2 x 15 m for 110 kV overhead lines. The "Energy Law" redefined the corridor widths as: 2 x 40 m for 400 kV and 220 kV overhead lines.

Density of housing was analysed by observing zones of the following widths:

- for 400 kV and 220 kV overhead lines: 2 x 25 m, 2 x 40 m, 2 x 80 m and 2 x 200 m;
- for 110 kV overhead lines: 2 x 15 m, 2 x 30 m, 2 x 75 m and 2 x 200.

According to the Rules on the assessment of the acceptability of the impact of implementation of plans and interventions in nature in protected areas, a maximum width of 200 m was defined.

Data about both existing and planned Slovenian transmission system is presented in Table 1.

TABLE 1 TRANSMISSION SYSTEM DATA

Rated voltage (kV)	400	220	110	∑
Corridor length of overhead lines (km)	417	299	1,202	1,918
Corridor length of planned overhead lines (km)	644	0	---	644

Analysis of Corridors and Discussion

Data about the location of our system was obtained from LIDAR (Laser Imaging Detection and Ranging) and is maintained in our GIS (Geographical Information System). The analysis included data on buildings, determined as polygons, provided by the Surveying and Mapping Authority of Slovenia. The data are incomplete and the analysis excluded all the buildings where information on the purpose of use is not known. Where at least part of the building is defined as residential, the analysis included the entire building. Analyses were made in a two dimensional layers with ESRI's ArcGIS® application. Each residential building was taken into account exactly once if it is inside the considered corridor or collides with it. The buildings in the inner corridor are always included in the number of the buildings in the wider corridor.

Number of houses in corridors of different widths for overhead lines of rated voltage 400 kV and 220 kV is presented in Table 2 and Figure 1. Number of houses in corridors for existing 110 kV can be seen in Table 3 and Figure 2.

TABLE 2 NUMBER OF HOUSES IN CORRIDORS OF 400 KV AND 220 KV OVERHEAD LINES

Width of the corridor (m)	2 x 25	2 x 40	2 x 80	2 x 200
Existing 220 kV overhead lines	209	412	1,007	3,179
Existing 400 kV overhead lines	132	261	688	2,385
Planned 400 kV overhead lines with alternatives	283	413	890	3,215
∑	624	1,086	2,585	8,779

Figure 1 and Figure 2 show that the number of houses grow exponentially with distance from the axis, consequently, the enlargement of corridors would require solving many issues related to a large number of houses.

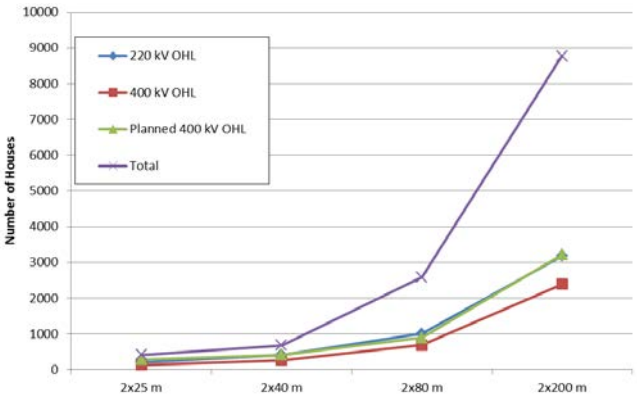

FIGURE 1 NUMBER OF HOUSES DEPENDENT ON VOLTAGE OF OVERHEAD LINE AND CORRIDOR WIDTH

TABLE 3 NUMBER OF HOUSES IN CORRIDORS OF 110 KV OVERHEAD LINES

Width of the corridor (m)	2 x 15	2 x 30	2 x 75	2 x 200
110 kV overhead lines	676	1,679	5,512	16,896

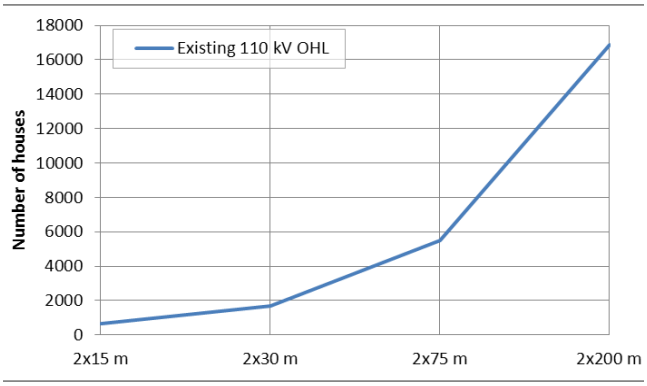

FIGURE 2 NUMBER OF HOUSES DEPENDENT ON CORRIDOR WIDTH FOR 110 KV OVERHEAD LINES

Figure 3 shows the data model used to count houses in the different corridors. Table 4 presents average data on the number of houses in differently sized corridors, the number of houses per hectare (not containing internal corridors) as well as the number of houses per kilometre of corridor. Figure 4 shows outcomes for 400 kV and 220 kV and in Figure 5 for 110 kV overhead lines.

Corridors are less densely settled than the area outside as we can see from Figure 4 and Figure 5. In case of 110 kV lines, the density of housing increases with the distance from the axis faster than that of 400 kV and 220 kV. We believe that 400 kV and 220 kV lines are less appealing to residents than 110 kV overhead lines. Another possible explanation for this would be that 110 kV lines are closer to city centres, so the housing density is therefore higher.

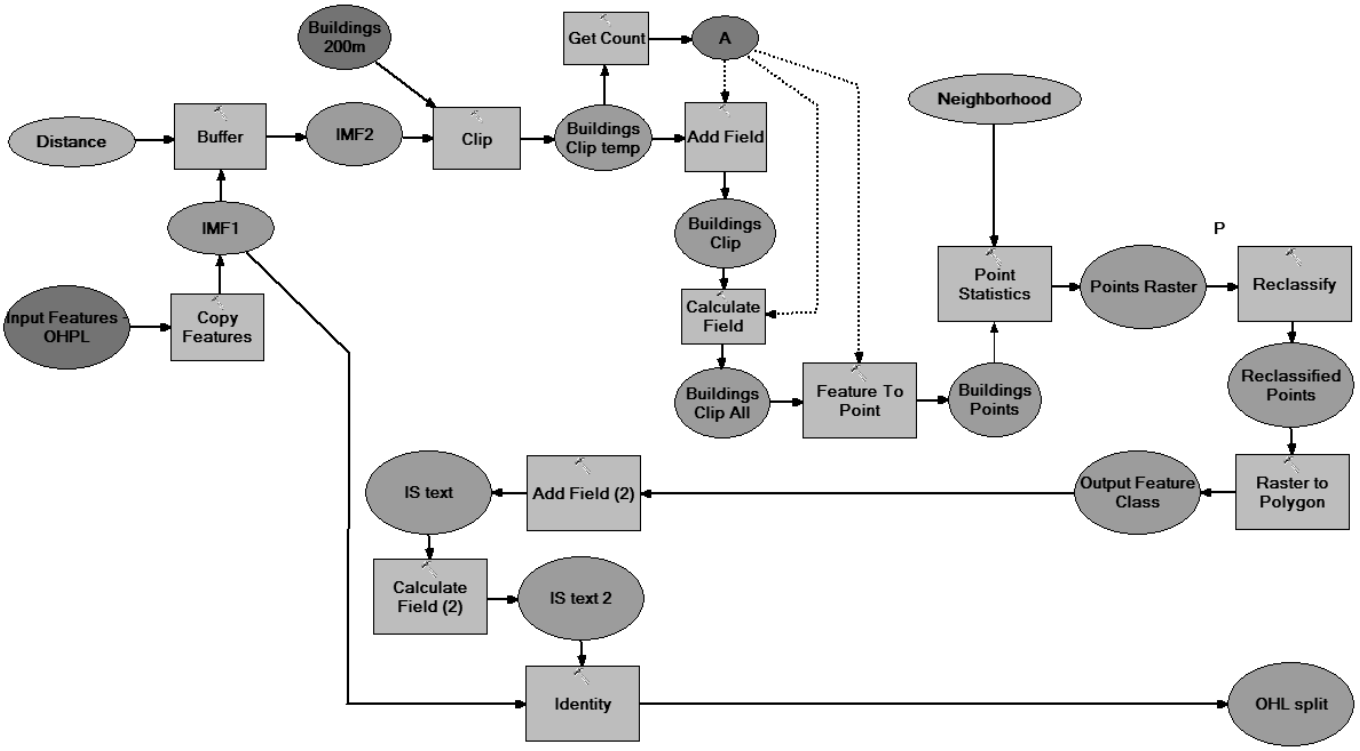

FIGURE 3 DATA MODEL FOR COUNTING HOUSES WITHIN CORRIDORS

TABLE 4 DENSITY OF HOUSING IN THE OVERHEAD TRANSMISSION LINE CORRIDORS

Corridor width (m)	Length (km)	No. of houses in 2 x 25 m	No. of houses per km	Houses per km of ext. cor.	Houses per ha of ext. cor.	No. of houses in 2 x 40 m	No. of houses per km	Houses per km of ext. cor.	Houses per ha of ext. cor.
Existing 220 kV	299	209	0.698	0.698	0.140	412	1.376	0.678	0.226
Existing 400 kV	417	132	0.317	0.317	0.063	261	0.627	0.310	0.103
Existing 400 kV and 220 kV	716	341	0.476	0.476	0.095	673	0.940	0.464	0.155
Planned 400 kV with alternatives	644	283	0.439	0.439	0.088	413	0.641	0.202	0.067
∑	2,076	624	0.301	0.301	0.060	1,086	0.523	0.223	0.074
Corridor width (m)	**Length (km)**	**No. of houses in 2 x 80 m**	**No. of houses per km**	**Houses per km of ext. cor.**	**Houses per ha of ext. cor.**	**No. of houses in 2 x 200 m**	**No. of houses per km**	**Houses per km of ext. cor.**	**Houses per ha of ext. cor.**
Existing 220 kV	299	1,007	3.363	1.987	0.248	3,179	10.617	7.254	0.302
Existing 400 kV	417	688	1.652	1.025	0.128	2,385	5.726	4.074	0.170
Existing 400 kV and 220 kV	716	1,695	2.367	1.427	0.178	5,564	7.771	5.404	0.225
Planned 400 kV with alternatives	644	890	1.382	0.741	0.093	3,215	4.992	3.610	0.150
∑	2,076	2,585	1.245	0.722	0.090	8,779	4.229	2.984	0.124
Corridor width (m)		**No. of houses in 2 x 15 m**	**No. of houses per km**	**Houses per km of ext. cor.**	**Houses per ha of ext. cor.**	**No. of houses in 2 x 30 m**	**No. of houses per km**	**Houses per km of ext. cor.**	**Houses per ha of ext. cor.**
Existing 110 kV	1,202	676	0.563	0.563	0.188	1,679	1.397	0.835	0.278
Corridor width (m)		**No. of houses in 2 x 75 m**	**No. of houses per km**	**Houses per km of ext. cor.**	**Houses per ha of ext. cor.**	**No. of houses in 2 x 200 m**	**No. of houses per km**	**Houses per km of ext. cor.**	**Houses per ha of ext. cor.**
Existing 110 kV	1,202	5,512	4.587	3.189	0.354	16,896	14.059	9.473	0.379

Density of houses near 220 kV lines is higher than near 400 kV lines (Figure 4). Possible explanations would be that 400 kV lines are less agreeable to residents than 220 kV ones and that in the past, a 400 kV corridor was wider than a 220 kV one. In addition, 220 kV lines were constructed before 400 kV lines so less attention

was paid to houses at that time. Near existing 400 kV lines, the density of houses is higher than near planned ones, which confirms that less thought was given to housing in the past than it is today.

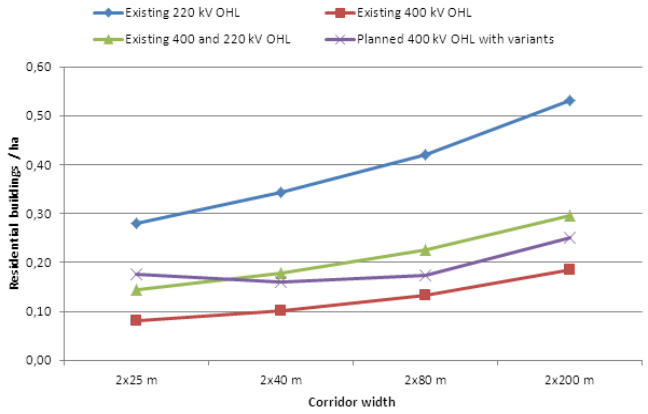

FIGURE 4 DENSITY OF HOUSING DEPENDENT ON CORRIDOR WIDTH FOR 400 KV AND 220 KV OVERHEAD LINES

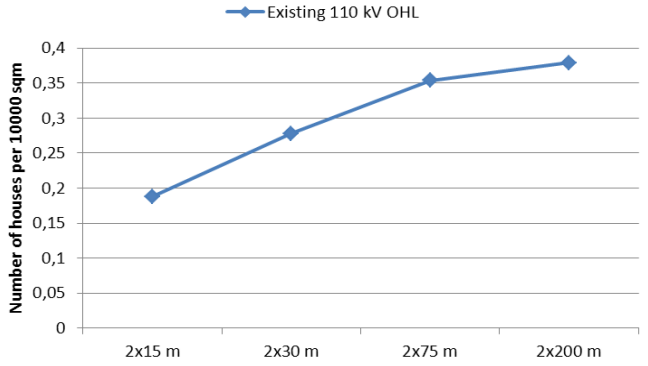

FIGURE 5 DENSITY OF HOUSING DEPENDENT ON CORRIDOR WIDTH FOR 110 KV OVERHEAD LINES

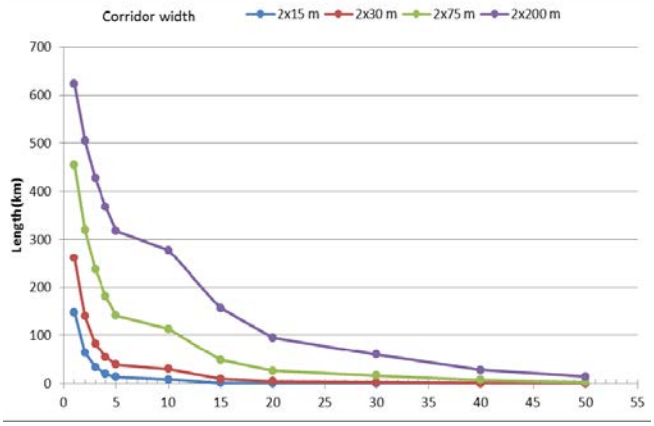

FIGURE 6 LENGTHS OF 110 KV OVERHEAD LINES DEPENDENT ON HOUSING CONCENTRATION

The density of housing in corridors of 110 kV overhead lines was analysed in detail. Figure 7 shows graphically how the influence of overhead line on houses is taken into account. In the first step, a buffer around residential building was made at distances of 15, 30, 75 and 200 m. The next step was to find the intersection between obtained polygons with the axis of each transmission line. At all intersections, we count the number of buildings buffers that intersect the axis of the transmission line. These values were then reclassified in predefined values classes. Defined classification is denser on a lower number of buildings, because in that area we try to determine the limit for number of buildings where the cabling makes sense. Data were exported to the tables and appropriately presented in tabular and graphical form in GIS. The calculations were performed for each line for all four distances from the axis of the transmission line. From Table 5 and Figure 6 we can conclude that a vast area of corridors is free of houses and just a small number of zones are settled (Kregar & Tomažič, 2011). We also summed all the segments where 1 house or more are closer to than 200 m, and the same for 3 houses or more, and the same for 5 houses or more. Results can be seen in the last three columns in Table 5.

Possible Solutions for the Problems of Housing in Overhead Line Corridors

In the 716 km long and 2 x 40 m wide corridor of 400 kV and 220 kV overhead lines there are 673 houses, which amount to 0.94 houses per kilometre. Cabling of overhead lines in the densely populated areas is a costly solution and also a technically unoptimal one. Moving houses from the line corridor would cost tens of millions of Euros. Widening of the line corridor would thus lead to a demand to move a large number of houses which would also amount to additional costs. Houses in existing overhead lines corridors fulfil all regulations. These are stricter for new lines so already in the time of planning, the problem of houses should be solved as well. Houses built before and after the construction of the overhead line were constructed in accordance with regulations, so both sets should be solved in the same way.

In the 1202 km long and 2 x 15 m wide corridor of 110 kV overhead lines there are 676 houses, which is equal to 0.563 houses per kilometre of corridor. Removing inhabitants from the corridors would amass to high costs, however widening the corridors would lead to even more residents needing to be removed from the corridor – consequently this would incur even higher costs, yet neither of the solutions could be financed from transmission fees.

Technology of cabling 110 kV overhead lines are currently less troublesome, more realisable and reasonably priced, and therefore we decided to study

the criteria for this voltage.

Higher voltage overhead lines have wider impacts than lower ones, so they should be given preferential treatment.

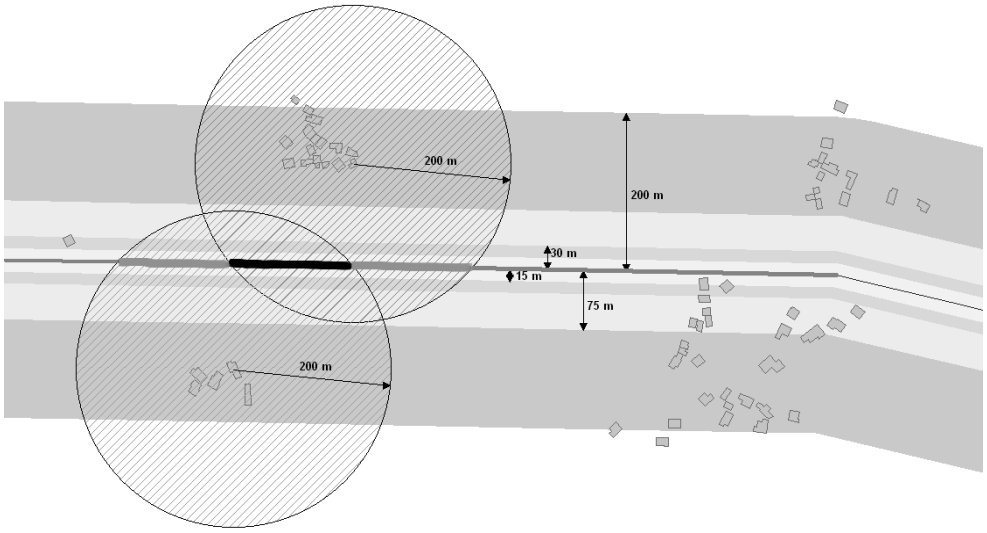

FIGURE 7 GRAPHICAL REPRESENTATION OF DETERMINING THE CONCENTRATION OF HOUSES IN CORRIDORS (GRAY SECTIONS ON THE AXIS OF OVERHEAD LINE REPRESENT THE INFLUENCE OF EXACTLY ONE HOUSE AND THE BLACK SECTION REPRESENTS THE INFLUENCE OF EXACTLY TWO HOUSES)

TABLE 5 LENGTH IN KILOMETRES, OF SEGMENTS OF 110 KV LINES DEPENDENT ON THE NUMBER OF HOUSES WITHIN A 200 M RADIUS FOR OBSERVED CORRIDOR WIDTHS

No. of houses	0	1	2	3	4	5	6…10	11…15	16…20	21…30	31…40	41…50	Min. 1	Min. 3	Min. 5
2 x 15 m	1,049.546	83.838	30.153	13.881	6.336	5.127	6.569	0.819	0.568	0.037	0.000	0.000	147.327	33.337	13.120
2 x 30 m	934.930	122.127	56.883	27.560	15.950	9.046	20.283	5.499	2.065	1.471	0.374	0.225	261.483	82.474	38.964
2 x 75 m	742.003	134.616	82.429	56.340	40.519	27.433	64.984	22.068	9.601	8.825	4.634	3.139	454.589	237.544	140.684
2 x 200 m	572.967	118.228	78.738	60.044	49.127	39.518	121.711	61.198	35.000	32.035	13.873	14.106	623.580	426.614	317.442

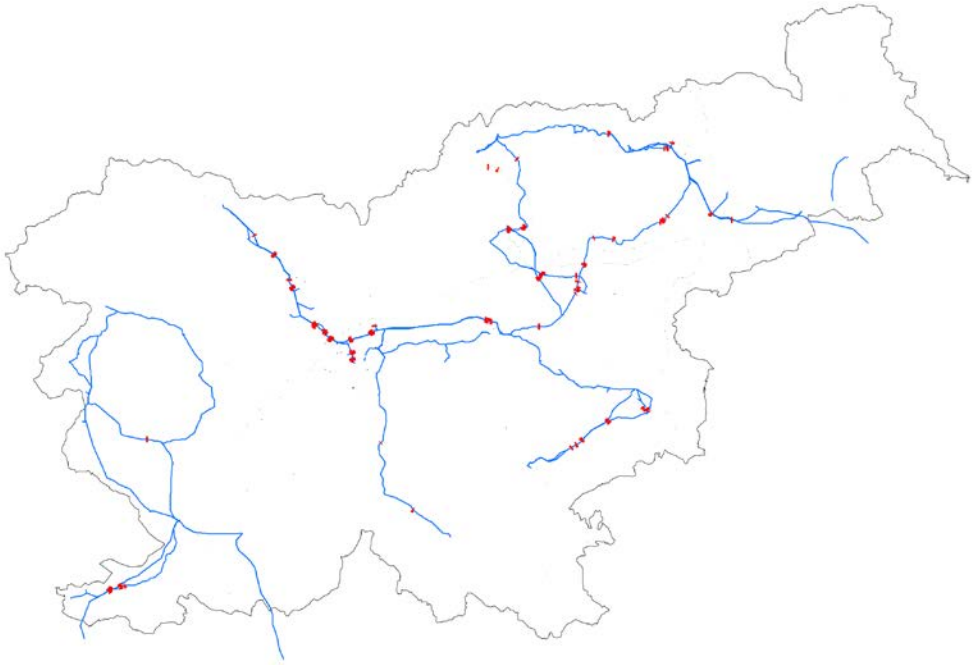

FIGURE 8 MAP OF SLOVENIA SHOWING SECTIONS OF 110 KV OVERHEAD TRANSMISSION LINES WHERE FIVE OR MORE HOUSES ARE CLOSER TO THE AXIS OF THE LINES THAN 200 M

Criteria for Cabling 110 kV Overhead Lines

Before we start setting criteria we must consider the physical principles, quality of supply, technological possibilities and accessible worldwide knowledge.

To reach public acceptance of criteria, they should be simple, understandable to the public, enable equality of residents living inside overhead line corridors and homogenous for Slovenia. Criteria should be in line with the standards of living that we can afford. In a way, criteria should also comply with public interest. Figure 6 shows that in wider corridors the housing density is higher and also that the lengths of inhabited sections increase along with widening of the corridors. We chose to pursue further analyses of the 2 x 15 m corridor, which comply with existing regulations, and are presented with the blue curve - the lowest curve - in Figure 6. Table 5 shows that there is no house closer than 200 m to 1050 km of 110 kV overhead line and there is at least one house closer than 200 m to 147 km of it. We can see that 33 km, or less than 3%, of all lines have a minimum of 3 houses closer than 200 m to the axis and that just 13 km of lines have a minimum of 5 houses closer than 200 m, which is less than 1 % of all lines. With GIS we located all this sections in Slovenia and presented them in Figure 8, from which we can see that there are few densely populated areas (Kregar & Tomažič, 2012). Figure 9 shows sections of overhead line with different housing density, where darker sections present areas with higher density. On the basis of these analyses, we prepared Table 6 which shows the 10 most populated areas in Slovenia close to 110 kV overhead lines.

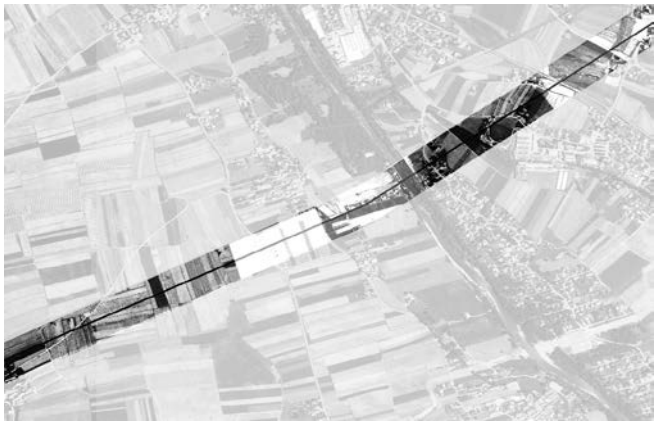

FIGURE 9 SECTION OF LINE WITH DIFFERENT HOUSING DENSITY; DARKER SECTIONS WITH HIGHER DESITY

Criteria should also consider the age of overhead lines since older ones should be cabled before newer ones as they are closer to the end of their operation. Criteria should also take into account the available part of transmission fees, which could be spent on investment in cabling these sections.

In some cases private investors have plans to build new development or building areas in the vicinity or on both sides of the existing overhead line. These initiatives are not taken in account and should be excluded from setting the cabling criteria. Such initiatives should not be obstructed unless they fail to fulfil technical requirements and transmission system operator's guidelines.

TABLE 6 LIST OF THE 10 LONGEST SECTIONS OF 110 KV OVERHEAD TRANSMISSION LINES WHERE AT LEAST 5 HOUSES ARE CLOSER THAN 200 M

No.	Name of the overhead transmission line	Length (m)
1	110 kV Laško-Podlog	880
2	110 kV Beričevo-Kleče (odsek Laze-Kleče)	811
3	110 kV Beričevo-Domžale-Kleče (odsek Laze-Kleče)	804
4	110 kV Slovenj Gradec-Velenje	659
5	2x110 kV TE TOL-Črnuče-Kleče	644
6	2x110 kV Kleče-Škofja Loka-Okroglo	563
7	110 kV Koper-Buje	563
8	110 kV Kleče-Medvode-(Mavčiče)-Labore-Okroglo II	552
9	110 kV Kleče-Medvode-(Mavčiče)-Labore-Okroglo II	543
10	110 kV Koper-Izola-Lucija	541

When preparing Table 5 we did not exclude sections which are shorter than 255 m, which is the average distance between adjacent towers of 110 kV overhead lines in Slovenia. From a technical and operational aspect, it is not sensible to cable such short sections and consequently we excluded them from further analyses; with these restrictions in mind, Table 6 was prepared. From this table we can also see that density of houses in the vicinity of 110 kV overhead lines is relatively small and appears in fairly short sections, not longer than 880 m.

Conclusion

Analyses confirm that the housing density increases steeply with the distance from the axis of the overhead line therefore enlarging the line corridor would cause additional problems for many houses which would consequently lead to higher costs.

Technically achievable criteria for cabling of overhead lines should be accepted by the public. That means that criteria should be clear, understandable and should take into account available financial funds. The problems of inhabitant relocation from the proximity

of overhead lines with higher rated voltage and older lines should be solved sooner. Furthermore, cabling should be executed primarily in areas with the highest housing density and should then gradually spread to the ones with lower population density.

Criteria on population density could also be applied to other types of linear infrastructures like gas and oil pipelines as well as roads. In areas with higher population density, broader mitigation measures should be implemented. Information on the population density could also be used in reverse, namely, when siting corridors in less populated areas.

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